Information Exchange in the Supply Chain *

Jayashankar M. Swaminathan †
Norman M. Sadeh
Stephen F. Smith

CMU-RI-TR-95-36

Carnegie Mellon University
The Robotics Institute

Technical Report

THE ROBOTICS INSTITUTE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
October 1995

3. REPORT TYPE AND DATES COVERED
technical

4. TITLE AND SUBTITLE
Information Exchange in the Supply Chain

5. FUNDING NUMBERS

6. AUTHOR(S)
Jayashankar M. Swaminathan, Norman M. Sadeh, Stephen F. Smith

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
The Robotics Institute
Carnegie Mellon University
Pittsburgh, PA 15213

8. PERFORMING ORGANIZATION REPORT NUMBER
CMU-RI-TR-95-36

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Advanced Research Projects Agency

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release;
Distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
In recent years, manufacturers have taken initiatives to integrate information within their supply chains in order to provide quick response to customer needs. In this paper, we study the influence of sharing supplier capacity information (such as availiable-to-promise (ATP)) on the performance of a supply chain. We consider a supply chain in which a manufacturer orders raw materials from two alternative suppliers differing in cost and capacity. We first derive the optimal inventory policy for the manufacturer under stochastic demand. Subsequently, using simulation, we compare different information sharing scenarios. Among other results our study shows that, while information sharing is beneficial to overall supply chain performance, in can be detrimental to individual entities in the supply chain. We find that when supplier adoption costs of the information system are negligible, the more expensive supplier makes less profits under information sharing. However, it is forced to share information. When adoption costs are substantial, our results indicate that it is better for the manufacturer to have information links with fewer suppliers (a subset of potential suppliers).

14. SUBJECT TERMS
supply chain, stochastic demand, supply uncertainty, available-to-promise (ATP) information, inter-organizational system (IOS) adoption

15. NUMBER OF PAGES
34 pp

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
unlimited	unlimited	unlimited	unlimited

Information Exchange in the Supply Chain *

Jayashankar M. Swaminathan †
Norman M. Sadeh
Stephen F. Smith
CMU-RI-TR-95-36

The Robotics Institute
Carnegie Mellon University
Pittsburgh, PA 15213-3891

October 1995

*This research was supported by Advanced Research Projects Agency under contracts #F30602-91-F-0016 and #F30602-90- C-0119 and, William Larimer Mellon Fellowship

†Graduate School of Industrial Administration and The Robotics Institute, Carnegie Mellon University, Pittsburgh, PA-15213.

Abstract

In recent years, manufacturers have taken initiatives to integrate information within their supply chains in order to provide quick response to customer needs. In this paper, we study the influence of sharing supplier capacity information (such as available-to-promise (ATP)) on the performance of a supply chain. We consider a supply chain in which a manufacturer orders raw materials from two alternative suppliers differing in cost and capacity. We first derive the optimal inventory policy for the manufacturer under stochastic demand. Subsequently, using simulation, we compare different information sharing scenarios. Among other results our study shows that, while information sharing is beneficial to overall supply chain performance, it can be detrimental to individual entities in the supply chain. We find that when supplier adoption costs of the information system are negligible, the more expensive supplier makes less profits under information sharing. However, it is *forced* to share information. When adoption costs are substantial, our results indicate that it is better for the manufacturer to have information links with fewer suppliers (a subset of potential suppliers).

Key words: Supply chain; stochastic demand; supply uncertainty; available-to-promise(ATP) information; inter-organizational system(IOS) adoption.

1 Introduction

In a highly competitive market, manufacturers face the challenge of reducing product development time, improving quality, and, reducing cost and leadtime for production. Their success in overcoming these challenges depends to a great extent on their ability to integrate individual plants (entities) into a tightly coupled supply chain. Management of material flow across several sites of the same enterprise is in itself quite challenging. This challenge is further complicated due to diverse (sometimes conflicting) interests of different entities in the supply chain. Recent studies [Helper and Sako(1995), Udo(1993), ECR(1993)] indicate that many manufacturers are sharing information (through inter-organizational information systems) with their suppliers to improve performance of the supply chain in terms of cost and customer service. For example, JC Penny installed a large-scale computerized inventory system to automatically reorder products from 281 suppliers, which accounted for more than 50 % of their business [Mayo(1986)]. However, the extent of benefits due to information sharing to different organizational entities is not well quantified. [Srinivasan et.al(1994), Cole and Yamakushiji(1984)] show in their empirical study that sharing information with the suppliers led to a significant improvement in the performance of Chrysler and Toyota respectively. However, [Cash and Konsynski (1985)] indicate that inter-organizational systems (IOS) in many cases, under the guise of faster information flow shifted inventory holding costs and business risks to suppliers.

In this paper, we study the influence of sharing supplier information on different organizational entities in the supply chain. We consider a manufacturer who procures components from two alternative suppliers while facing stochastic demand for a single product. Suppliers differ in terms of cost and available-to-promise (ATP) capacity. The more expensive supplier shows less variation in the capacity allocation as compared to the other supplier. We consider a discrete time single period problem where sequence of events is as follows- (1) Suppliers calculate the ATP quantity and assemble components to satisfy the ATP demand. (2) Manufacturer places an order with one or more suppliers. In case, ATP information is shared then it uses that information while ordering, otherwise, it uses an approximation based on historical data. (3) Suppliers deliver the order in full or part based on the order size. They incur a holding cost for left over inventory and stock-out cost for unsatisfied demand (no backlogging). (4)

Manufacturer converts raw inventory received from suppliers into finished products. (5) Demand occurs at the end of the period. Manufacturer uses finished products to satisfy demand. Holding cost is incurred on excess inventory (carried to next period) and stock-out cost for unsatisfied demand (no backlogging). We derive the optimal inventory policy that minimizes expected cost incurred by the manufacturer under above conditions. We also provide a newsboy interpretation to the policy and generalize it to multiple suppliers.

In our computational study (with two suppliers), we simulate the inventory policy for a large number of periods under different demand scenarios and capacity allocations by suppliers. We compare performance in terms of costs incurred by the manufacturer, profits of suppliers and percentage of demand satisfied for alternative models of information sharing (of supplier ATP capacity)- (1) information links with both suppliers, (2) information link with one supplier and (3) information links with no supplier. Our results indicate that the supply chain performs better in terms of cost and quality of services (measured in terms of percentage of demand satisfied on time) under information sharing. We find that information sharing improves performance of the manufacturer and the less expensive supplier. We also find that the more expensive supplier is *forced* to share information though information sharing is not of inherent advantage to it. Subsequently, we analyze the impact of introduction of supplier adoption costs (cost to set-up and maintain information links). [Klein(1992) and Kelleher(1986)] indicate that manufacturers, in practice, pay a subsidy (increase in price paid per component) to suppliers in order to compensate them for incurring additional investment for information sharing. Also, amount of subsidy (increase in price) is directly related to cost incurred by suppliers to adopt the information system. In our computational study, we vary the amount of subsidy given by the manufacturer in alternative models of information sharing. Our results indicate that if cost of adoption of the information system is relatively large (higher subsidy) then it is better for the manufacturer not to have information links with any of the suppliers. However, under lower adoption costs it is better for the manufacturer to set-up information links with one or both the suppliers. Further our results indicate that the manufacturer is more likely to maintain information links with suppliers when there is greater uncertainty in the supply process.

Literature related to supply chain analysis have indicated that dynamics associ-

ated with a supply chain can be extremely complex [Lee and Billington (1992)] and in most cases, can be empirically verified only through simulation. [Cohen and Lee(1988)] present a comprehensive approximation of a supply chain model that incorporates raw materials, production and a distribution system and provide valuable insight into dynamics of supply chains where demands are stochastic and all locations use reordering policies specified by two numbers (i.e. (s,S) or (Q,R)). [Pyke and Cohen (1993),(1994)] study a three stage linear integrated production-distribution system, develop the distribution for key random variables, and discuss managerial insights that arise from the analysis. In this paper, we use simulation to study the influence of information sharing on the supply chain. Comparative analysis of diversification strategies for the manufacturer under supply uncertainty are discussed in [Moinzadeh and Nahmias(1988), Ramasesh et.al (1991)(1993), Lau and Lau(1994)]. [Anupindi and Akella(1993)] study a model where a manufacturer facing uncertain demand procures a component from two alternative suppliers. One of the suppliers is more expensive than the other in terms of cost but is more reliable in terms of delivery. The authors derive optimal inventory policy for the manufacturer under different scenarios (corresponding to shipments from suppliers) for single and multiple period problems. Our model is related to the above model, however, we additionally include capacity restrictions on suppliers and analyze the influence of information sharing in such a situation. Inter-organizational information systems have been studied predominantly using economic models [Riggins et al.(1994), Marcus(1990), Oren and Smith(1981)]. These models consider utility function of the user to join the information network. [Wang and Seidmann(1995)] use an economic model to study the influence of electronic data interchange (EDI) and its adoption by suppliers. They consider a downward sloping deterministic demand for the manufacturer. They find that it is optimal for the manufacturer to adopt EDI with fewer suppliers when the supplier adoption costs are high. Interestingly, in this paper we find a similar result in the computational study. In our problem, the manufacturer faces stochastic demand, shares ATP information and, optimizes ordering, stock-out and inventory costs.

The rest of the paper is organized as follows. In section 2, we describe the conceptual model and our hypotheses. Subsequently, we develop the basic analytical model. We derive the optimal inventory policy and generalize it to multiple suppliers. In section 3, we describe alternative models of information sharing and supplier adoption costs. In

section 4, we discuss our computational results. In section 5, we present our concluding remarks and identify opportunities for future research.

2 Basic Model

In this section, we first introduce the conceptual model. Subsequently we formulate a basic analytical model. We derive the optimal inventory policy for the manufacturer. We also provide a newsboy interpretation to the policy and generalize our results to multiple suppliers.

2.1 Conceptual Model

Recent studies have shown that quick propagation of relevant information can enhance the performance of a supply chain to a great extent [Udo(1993)]. Information transfer in one form or the other occurs between every pair of interacting entities in a supply chain, differing only in the type and time of sharing of information. In this study, we consider a manufacturer who orders goods from two alternate suppliers. The information that is being shared is the ATP capacity of suppliers for this manufacturer. The manufacturer orders goods from suppliers in each period after incorporating supplier information in the reordering policy.

Information sharing can have beneficial or detrimental effect on an entity depending on the type of information shared and with whom it is shared. We have identified three basic hypotheses with respect to exchange of supplier information which are as follows.

- *H1: Supplier information sharing leads to better performance in the supply chain both in terms of cost and quality of service.*
  Empirical evidence has indicated that sharing information on demand forecasts and delivery of shipments has significantly improved the performance of the supply chain at Chrysler [Srinivasan et.al (1994)] and Toyota [Cole and Yamakushiji (1984)]. We feel that supplier information should also have a similar effect because it reduces the amount of uncertainty in the system.

- *H2: Supplier information sharing is beneficial to all the organizational entities in the supply chain.*
  In our model, we incorporate supplier information in the reordering decision

process of the manufacturer. Information sharing reduces the uncertainty in the supply process, and as a result, we feel that it would be beneficial to all entities, though the degree of benefit may vary. However, [Cash and Konsynski (1985)] cite examples where information sharing shifted inventory holding costs and business risks to the supplier.

- *H3: Suppliers would be willing to share information.*
  This hypothesis is based on the empirical evidence which shows that there is a significant increase in the number of suppliers who shared information with the manufacturer in the last decade [Helper(1991), Helper and Sako(1995)].

In order to evaluate these hypotheses, we first develop a basic model for manufacturer/supplier interaction in a simple two-tiered supply chain, and establish an optimal ordering policy for the manufacturer. We then use the basic model to define a series of more specialized models, each making different assumptions about the extent and cost of supplier information exchange. Through simulation we evaluate each of these models and relate results obtained to hypotheses identified above.

2.2 Analytical Model

In the basic model, we consider a supply chain in which there is a single manufacturer who orders goods from two suppliers. Suppliers differ in cost and the capacity allocated for the manufacturer. We assume that suppliers can procure raw material immediately and supply them in the same period. However, they have a limited capacity which determines the ATP quantity. This quantity is perceived as a stochastic allocation by the manufacturer because it changes from period to period. The fluctuations in capacity allocations occur because suppliers face demand from other manufacturers as well. We do not address the issue as to how capacity allocation is done at the supplier's end. In order to keep the analysis tractable we assume that for a particular manufacturer the allocation in each period is a random variable from a stationary distribution. The distribution corresponding to the less expensive supplier has more variance for the same mean value.

To formulate the model more precisely, we use the following notations:

- ξ: random demand for the manufacturer in a period.

- C_i: available-to-promise capacity of supplier i in a period.
- p_i: cost of procuring the component from supplier i.
- x: on-hand inventory for the manufacturer at the start of a period.
- w_i: quantity ordered from supplier i in a period.
- $\beta_i(w_i)$: 0-1 variable indicating whether the whole quantity w_i would be received from supplier i. $\beta_i(w_i) = 1$ indicates that w_i would be received completely.
- $\overline{\beta}_i(w_i)$: $1 - \beta_i(w_i)$.
- γ_i: quantity that is expected from supplier i when $\beta_i(w_i) = 0$.
- π: per unit per period stock-out cost for the manufacturer.
- h: per unit per period holding cost for the manufacturer.
- μ_i: mean of C_i.
- σ_i: standard deviation of C_i.
- $f(\xi)$: probability density of ξ.
- $F(\xi)$: cumulative density of ξ.
- $M(x, w_1, w_2)$: expected cost incurred by the manufacturer in a single period when the on-hand inventory is x and w_1, w_2 quantities are ordered from the suppliers.

We consider a single period model where the manufacturer minimizes expected cost incurred $M(x, w_1, w_2)$. $M(x, w_1, w_2)$ consists of- (1) cost of procuring the component from suppliers, (2) cost of carrying excess inventory or holding cost at the rate of h per item and (3) cost of falling short of the demand or the stock out cost at the rate of π per item. In any given period, the following sequence of events takes place:

- Suppliers calculate the ATP quantity C_i and assemble components to satisfy the ATP demand.
- Manufacturer places an order with one or more suppliers based on the current inventory level x and supplier capacity information. When ATP information is available the maximum amount that could be expected (γ_i) is C_i i,e $\gamma_i = C_i$.

- Suppliers deliver the order in full or part based on the order size. They incur a holding cost for left over inventory and stock-out cost for unsatisfied demand (no backlogging).
- Manufacturer pays for goods received and converts them into finished products.
- Demand ξ occurs at the end of the period. Manufacturer uses the finished inventory to satisfy demand. Holding cost is incurred on excess inventory (carried to the next period) and stock-out cost for unsatisfied demand (no backlogging).

2.2.1 Single Period Cost Function for the Manufacturer

The expected cost incurred by the manufacturer is given by the equation below.

$$\begin{aligned} M(x,w_1,w_2) &= p_1 w_1 \beta_1(w_1) + p_2 w_2 \beta_2(w_2) + p_1\gamma_1\overline{\beta}_1(w_1) + p_2\gamma_2\overline{\beta}_2(w_2) \\ &\quad + \pi.\sum_y \phi(w_1,w_2,y).\int_y^{\infty}(\xi-y)f(\xi)d\xi \\ &\quad + h.\sum_y \phi(w_1,w_2,y).\int_0^{y}(y-\xi)f(\xi)d\xi \end{aligned}$$

where,

$$\phi(w_1,w_2,y) = \begin{cases} \beta_1(w_1).\overline{\beta}_2(w_2) & if \quad y = x + w_1 + \gamma_2 \\ \beta_1(w_1).\beta_2(w_2) & if \quad y = x + w_1 + w_2 \\ \overline{\beta}_1(w_1).\overline{\beta}_2(w_2) & if \quad y = x + \gamma_1 + \gamma_2 \\ \overline{\beta}_1(w_1).\beta_2(w_2) & if \quad y = x + \gamma_1 + w_2 \\ 0 & if \quad otherwise \end{cases}$$

The function $\phi(w_1, w_2, y)$ indicates the probability that on-hand inventory with the manufacturer is y after orders have been received (the on-hand inventory before ordering was x) given that it ordered w_1 and w_2 items from suppliers. For example, if the on-hand inventory with the manufacturer after orders arrive is $x + w_1 + w_2$, then both suppliers supplied the whole quantity. Thus, the value of ϕ is given by $\beta_1(w_1).\beta_2(w_2)$, which is the probability that both suppliers supply the whole quantity w_i.

The cost of ordering w_i items from each of the supplier is either $p_i.w_i$, in case the manufacturer expects to receive the whole quantity (w_i) or $p_i.\gamma_i$, when the manufacturer expects that the supplier would supply only γ_i. The expected cost of holding

inventory given that y is the on-hand inventory after orders have been received is given by $h.\int_0^y (y-\xi)f(\xi)d\xi$ where the integral term represents expected number of leftover items after the demand ξ is satisfied. The total expected inventory holding cost is obtained by multiplying the above cost by the probability of realizing the value y given by $\phi(w_1, w_2, y)$ and summing over all possible values of y. Similarly, expected cost of stock-out given that y is the on-hand inventory after orders have been received is given by $\pi.\int_y^\infty (\xi - y)f(\xi)d\xi$ where the integral term represents expected number of items that were stocked out. The total expected cost of stock out is obtained by multiplying the above cost by the probability of realizing the value y given by $\phi(w_1, w_2, y)$ and summing over all possible value of y. Recall that β_i is a 0-1 variable as a result only four values of y are feasible.

Proposition 2.1 : The single period expected cost function is convex.
Proof: Refer Appendix-I.

2.2.2 Inventory Policy for the Manufacturer

In this section we derive the optimal inventory policy for the manufacturer.

Proposition 2.2 : If the single period expected cost function $M(x, w_1, w_2)$ is convex then there exist numbers $w_{1a}^*, w_{2a}^*, w_{1b}^*, a$ and b such that the optimal procurement policy has the structure as follows :-

$$(w_1^*, w_2^*) = \begin{cases} (w_{1b}^*, w_{2a}^*) & if \quad x < b \\ (w_{1a}^*, 0) & if \quad a > x >= b \\ (0, 0) & if \quad x >= a \end{cases}$$

Proof: Refer Appendix-I for the proof of the existence of a solution and the values of $w_{1a}^*, w_{2a}^*, w_{1b}^*, a$ and b. These values are as follows.

$$\begin{aligned} a &= F^{-1}(\frac{\pi - p_1}{\pi + h}) \\ b &= F^{-1}(\frac{\pi - p_2}{\pi + h}) - \gamma_1 \\ w_{1a}^* &= min(\gamma_1, F^{-1}(\frac{\pi - p_1}{\pi + h}) - x) \end{aligned}$$

$$
\begin{aligned}
w_{1b}^* &= \gamma_1 \\
w_{2a}^* &= min(\gamma_2, F^{-1}(\frac{\pi - p_2}{\pi + h}) - x - \gamma_1)
\end{aligned}
$$

The policy indicates that there are three distinct regions in which the inventory could fall, based on which, the manufacturer decides to place orders with suppliers. In case the manufacturer has enough on-hand inventory ($x > a$), it does not place an order. If the on-hand inventory is more than b but less than a then orders are placed with the less expensive supplier and orders are placed with both suppliers if on-hand inventory is less than b..The structure of our policy is similar to the policy obtained by [Anupindi and Akella(1993)]. However, they consider infinite capacity and constant reliability factor β_i (not dependent on the order quantity) for each of the suppliers. As a result, the boundary values (a and b) as well as the order quantities are different in the two models.

The inventory policy indicates that an increase in variance of demand leads to an higher value for both a and b (refer Figure 1). However, the increase in a is greater than that of b because $p_1 < p_2$. As a result, the difference between a and b increases. Recall that this difference is the region where components are ordered only from the less expensive supplier. Thus, increase in the variance of demand leads to higher business volume for the less expensive supplier. It should be noted that the region where components are ordered from both suppliers also increases (due to increase in b). Thus, an increase in variance of demand leads to larger orders for suppliers. An intuitive explanation for the above is that increase in variance of demand forces the manufacturer to keep more safety stock which in turn leads to larger orders for suppliers.

Boundaries defining the three regions are adjusted over time depending on supplier$_1$'s ATP capacity information (when available). The value of b increases or decreases depending on the capacity allocation of the less expensive supplier. If the capacity allocation of the less expensive supplier is greater than the previous period (the value of b decreases) then the manufacturer orders more from that supplier. On the other hand, if the capacity allocated is less than the previous period (value of b increases) then the manufacturer orders from both suppliers.

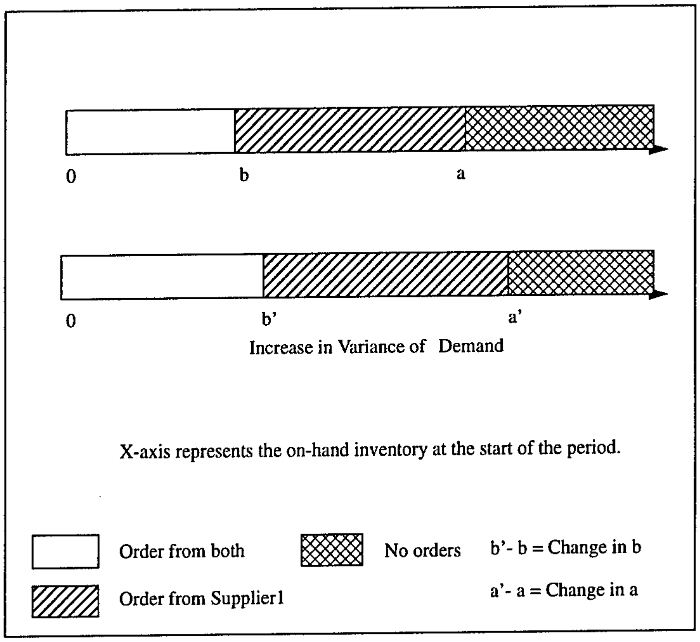

Figure 1: Sensitivity Analysis with respect to Variance of Demand

2.2.3 Newsboy Interpretation and Generalization to N Suppliers

The inventory policy has a recursive newsboy structure. The policy operates in the following manner. First the reordering point is calculated with p_1 as the cost of procuring components. This gives the reordering point $y = F^{-1}(\frac{\pi-p_1}{\pi+h})$. If the cheaper supplier has enough capacity (i,e $\gamma_1 \geq F^{-1}(\frac{\pi-p_1}{\pi+h}) - x$) then orders are placed only with the cheaper supplier for $y-x$; otherwise, maximum amount γ_1 is ordered from the cheaper supplier. Next, the reordering point is calculated with p_2 as the cost of procuring components which gives $y = F^{-1}(\frac{\pi-p_2}{\pi+h})$. The on-hand inventory is now equal to $x+\gamma_1$. If the more expensive supplier has enough capacity (i,e $\gamma_2 \geq y-(x+\gamma_1)$) then orders are placed for $y-(x+\gamma_1)$; otherwise orders are placed for γ_2.

Note that in the above inventory policy there exists a region such that $F^{-1}(\frac{\pi-p_2}{\pi+h}) - \gamma_1 < x < F^{-1}(\frac{\pi-p_1}{\pi+h}) - \gamma_1$ where the policy selects $w_1 = \gamma_1$ and $w_2 = 0$ though supplier$_2$ may have enough capacity to bring the inventory level to $F^{-1}(\frac{\pi-p_1}{\pi+h})$ (i,e $\gamma_1+\gamma_2+x > F^{-1}(\frac{\pi-p_1}{\pi+h})$). An intuitive explanation for this result is that once the manufacturer starts procuring components from supplier$_2$, the target inventory level changes to $F^{-1}(\frac{\pi-p_2}{\pi+h})$. However, in the above region $x+\gamma_1 > F^{-1}(\frac{\pi-p_2}{\pi+h})$, thus no

- Arrange the suppliers in a list according to their cost (in ascending order).
- Initialize $i = 1$ (i is the index to the ith supplier in the above list). Set Completed = FALSE. Set $w_i = 0$ for all i.
- While (not Completed)
  - Compute $a_i = F^{-1}(\frac{\pi - p_i}{\pi + h}) - \sum_{j=1}^{i-1} \gamma_i$.
  - If $x \leq a_i$
    * Compute $w_i = min(\gamma_i, a_i - x)$.
    * i = i+1.
    * If $((i > N)$ OR $(w_i < \gamma_i$) then Completed = TRUE.
  - else
    * Completed = TRUE.
- Return w_i for all i.

Figure 2: Reordering Policy for Multiple Supplier Case.

orders are placed with supplier$_2$.

The above newsboy interpretation facilitates the generalization of this policy to multiple suppliers. Let $a_1..a_N$ correspond to the N boundary points that define the reordering policy. For example, in a two supplier case, $b = a_2$ and $a = a_1$. Orders are placed with supplier i if the on-hand inventory is less than a_i. Let $\gamma_1..\gamma_N$ and $p_1..p_N$ correspond to the capacities and the prices of the N suppliers where p_1 is the least cost. $w_1..w_N$ represent orders placed with the N suppliers. Then the above reordering policy can be stated as follows (note that $w_i > 0$ only when $x < a_i$):

$$\begin{aligned} a_i &= F^{-1}(\frac{\pi - p_i}{\pi + h}) - \sum_{j=1}^{i-1} \gamma_i \\ w_i &= min(\gamma_i, a_i - x) \end{aligned}$$

The inventory policy can be implemented using the algorithm shown in Figure 2. At each step, orders are placed with least cost supplier available and when the inventory level becomes higher than the 1 point, no further orders are placed.

2.2.4 Inventory Policy for the Suppliers

Suppliers face demand from more than one manufacturer at the same time. They employ capacity planning and allocate their capacity among manufacturers. Capacity allocation is based both on past demands as well as on cost-benefit analysis for the supplier. Operations strategy of the supplier is to produce up to the capacity allocated for each of the manufacturer. This ensures that the supplier defaults only when there is excess demand (i,e the supplier does not default due to other factors such as lack of raw materials). If the supplier gets an order less than the capacity allocated then it supplies the whole quantity, otherwise, it supplies up to the capacity allocated for the manufacturer. The supplier incurs a cost (which consists of cost of ordering, holding and stock-out) in each time period. In our computational study, we generate a random number from a stationary distribution to model the capacity allocation of the supplier for the manufacturer considered in the model. We restrict our attention to the cost incurred by the supplier due to that manufacturer. These cost figures help in the comparison of supplier's performance under different scenarios that are considered.

3 Special Cases of the Basic Model

In this section, we describe five special cases of the basic model that we analyze in this paper. First three cases (Model-I, Model-II and Model-III) ignore supplier adoption costs and differ only in the extent of information sharing between the manufacturer and suppliers. Subsequently, we introduce price subsidies in Model-IIs and Model-IIIs to incorporate supplier adoption costs.

3.1 No Information Links (Model-I)

In this section, we consider a manufacturer that does not have information (ATP) links with suppliers. Such a situation is very common in inter-organizational supply chains. While making decisions on how much to order from each of the suppliers the manufacturer uses expected value of capacity allocation(μ_i) to determine γ_i (maximum quantity that the supplier can be expected to fulfill). The manufacturer could employ a more sophisticated model for calculating γ_i if the statistical distribution of the supplier allocations are available. However, the allocation depends on various exogenous factors and as a result the distribution is difficult to compute and is not available to the manufacturer. Our experience indicates that in practice, the average allocation value

is the best approximation that the manufacturer has based on previous history. Thus, reordering decisions are made under the assumption that $\beta_i(w_i)$ is equal to one if $w_i \leq \mu_i$ and it is equal to zero if $w_i > \mu_i$. Recall that inventory policy for the manufacturer is defined by values of a, b, w^*_{1a}, w^*_{1b} and w^*_{2a}. For Model-I, these values are computed by substituting $\gamma_i = \mu_i$ (refer section 2.2.2).

3.2 Symmetric Information Links (Model-II)

In this section we consider a manufacturer that has information (ATP) links with both suppliers. Many inter-organizational supply chains including grocery chains are striving to incorporate information systems which will enable quick and easy access of ATP and forecast information of other entities in the supply chain. In such an environment, the manufacturer knows supplier's capacity at the time of placing orders. This information is incorporated while calculating the order quantities. The manufacturer changes the ordering policy in a dynamic fashion depending on the capacity allocation (C_i) of suppliers. Reordering decisions are made under the assumption that $\beta_i(w_i)$ is equal to one if $w_i \leq C_i$ and it is equal to zero if $w_i > C_i$. The inventory policy for the manufacturer is obtained by substituting $\gamma_i = C_i$ and computing the values of a, b, w^*_{1a}, w^*_{1b} and w^*_{2a}.

3.3 Asymmetric Information Links (Model-III)

In this section we consider a scenario where the manufacturer adopts information links only with the less expensive supplier. The rationale behind such a strategy is that the inventory policy of the manufacturer depends to a greater extent on C_1 than on C_2. The values of b, w^*_{1a}, w^*_{2a} and w^*_{1b} depend on C_1 whereas only w^*_{2a} and w^*_{1b} depend on C_2. The above strategy is optimal for the manufacturer when sharing information with both suppliers is not economically feasible or when the more expensive supplier refuses to adopt the information system. The reordering decisions are made with asymmetric information about the capacity allocations. Capacity allocation of the less expensive supplier is known exactly whereas the capacity allocation of the more expensive supplier is not known exactly. Reordering decisions are made under the assumption that $\beta_1(w_1)$ is equal to one if $w_1 \leq C_1$ and it is equal to zero if $w_1 > C_1$ and, $\beta_2(w_2)$ is equal to one if $w_2 \leq \mu_2$ and it is equal to zero if $w_2 > \mu_2$. The inventory policy for the manufacturer is obtained by substituting $\gamma_1 = C_1$ and $\gamma_2 = \mu_2$ and computing the values of a, b, w^*_{1a}, w^*_{1b}

and w^*_{2a}.

3.4 Price Subsidies (Model-IIs and Model-IIIs)

In this section, we discuss various costs that have been attributed to adoption of information systems in the supply chain. Subsequently, we introduce two additional models that incorporate price subsidies for suppliers.

Adoption of a new technology such as electronic data interchange (EDI) leads to different types of costs [Hornback(1994)]. These costs can be classified into four major categories given below.

- Personnel: These costs are related to hiring employees in order to maintain a information system.
- Training: These costs are incurred during the initial phase of the adoption when major training sessions are conducted for the employees.
- Software: Software costs mainly consists of purchasing, customizing and maintaining the software. Typically, the base price of software has reduced in the last few years. However, costs for customizing could be high in some cases when the translation software to interface with trading partner's proprietary information is expensive [Kelleher (1986)].
- Communication: Communication costs are costs incurred per transaction (time during which the phone line is utilized and the 2 time on the machine).

Hardware costs are one-time set up costs that are incurred in the initial phase of the information system adoption. The costs of adoption of an information system for a supplier mainly consists of personnel and software costs. These include translation costs (from in-house to EDI format), security and syntax control, network services etc. Supplier adoption costs vary depending on the information systems already present with the supplier[Wang and Seidmann(1995)].

In practice, many large firms subsidize their suppliers for the cost of implementing information systems at least in the initial phases [Klein(1992)]. Subsidies can also be considered as means of profit sharing within the supply chain. These subsidies depend

to a great extent on the initial cost of setting up and maintaining the information system. We consider two additional models - Model-IIs and Model-IIIs which are similar to Model-II and Model-III described earlier. However, both Model-IIs and Model-IIIs include per unit price subsidies (δp) for suppliers who adopt information links. Thus, in Model-IIs there is a price increase for both suppliers ($p_i^s = p_i + \delta p$) and in Model-IIIs there is a price subsidy only for the less expensive supplier ($p_1^s = p_1 + \delta p$ and $p_2^s = p_2$).

Our original motivation for considering adoption costs and price subsidies came from the observation that many manufacturers have extensive information links with their suppliers while others do not have such links. We conducted a computational study of our two-level model to get insights as to when manufacturers may have an incentive to adopt extensive links with their suppliers.

4 Computational Analysis and Insights

In this section, we describe our experimental setup and provide insights based on the results of our computational analysis.

4.1 Experimental Design

The computational study was carried out in an object oriented discrete event simulation framework. The entities in the supply chain were modeled as objects and the communication was captured using messages. The demand distribution as well as the distribution functions of the capacity allocations were assumed to be normal. In our study, we varied the standard coefficient of variation (scv = standard deviation/ mean) of demand and the standard coefficient of variation(scv) of capacity allocation of supplier$_1$. The scv of demand for the supply chain was set to be 0.125, 0.25 and 0.375. For each of these scv value, the scv of capacity allocation of supplier$_1$ was changed from 0.125 to 0.375 (in ten equal steps). Each of these configurations was run 10 times, each time using a different set of seeds for random number generation. We ran each of the problems for 100 periods. An increase in the scv of the capacity of supplier$_1$ implies an increase in the variability of supplier$_1$'s deliveries to the manufacturer. Supplier$_1$ is the cheaper supplier and hence shows more variability than supplier$_2$. Thus, scv of the capacity allocation of supplier$_2$ was set at 0.125 in all the experiments.

Table 1 shows the parameter values used in the simulation. The holding cost per item of inventory per unit period for the manufacturer was set at 6% of the price per item of goods sold and for the suppliers at 10%. The stock-out cost for the manufacturer was set at 30% of the price of goods, whereas for the supplier_1 it was 13% and for supplier_2 it was 18%. The above cost percentages were chosen based on our discussion with managers in the computer industry. The stock out cost of supplier_2 is higher because it is considered more reliable than supplier_1. Also, the manufacturer incurs a higher stock-out cost due to proximity to the end-customer.

	Mean Demand = 80			
	Mean Capacity	Holding Cost	Penalty Cost	Price of Goods
Manufacturer	-	\$ 3.0	\$ 15.0	\$ 50.0
Supplier_1	40	\$ 0.45	\$ 0.60	\$ 4.5
Supplier_2	40	\$ 0.55	\$ 0.90	\$ 5.5

Table 1: Cost and capacity values used in simulation.

All our results (shown in Tables 2-8) are average values of 10 simulation runs. Cost incurred at any site was measured as the sum of cost of purchasing raw materials, inventory holding costs and stock-out costs. Performance of the model was measured in terms of the total cost incurred by the manufacturer, the system as a whole, profits of the suppliers and the percentage of demand that was satisfied by the supply chain. We did not consider the costs incurred by the suppliers as a performance measure because their values are very small (because of the parameters chosen) and hence, they do not provide much insights.

4.2 Basic Effects of Information Exchange

We conducted a pilot study to understand the effect of information sharing on the different entities in the supply chain as well as the overall performance of supply chain. The scv of demand and capacity allocation of the supplier_1 were changed as described in section 4.1. We compared the performance of symmetric information sharing (Model-II) to no information sharing (Model-I). We find the following results:

SCV. of Demand	Model-I Total Cost	Model-I Man. Cost	Model-I Service (%)	Model-II Total Cost	Model-II Man. Cost	Model-II Service (%)
0.125	13357	48240	90.0	11823	47033	91.4
0.250	19203	52890	86.1	17934	51900	87.4
0.375	26063	58250	81.6	24900	57295	82.8

Table 2: Performance of the supply chain when scv of supplier$_1$'s capacity = 0.25

σ_1/μ_1	Total Cost	Man. Cost	Service (%)	Supplier$_1$'s Profit	Supplier$_2$'s Profit
0.15	18587	52319	86.7	16347	17384
0.20	19340	52788	86.1	15959	17488
0.25	20205	53334	85.4	15561	17568
0.30	21112	53917	84.7	15152	17652
0.35	21961	54465	84.4	14804	17700

Table 3: Performance of the supply chain under Model-I when scv of demand = 0.25

σ_1/μ_1	Total Cost	Man. Cost	Service (%)	Supplier$_1$'s Profit	Supplier$_2$'s Profit
0.15	16999	51381	88.4	17623	16758
0.20	17440	51620	87.7	17708	16471
0.25	17933	51900	87.3	17779	16180
0.30	18483	52221	86.7	17850	15886
0.35	19088	52591	86.4	17895	15607

Table 4: Performance of the supply chain under Model-II when scv of demand = 0.25

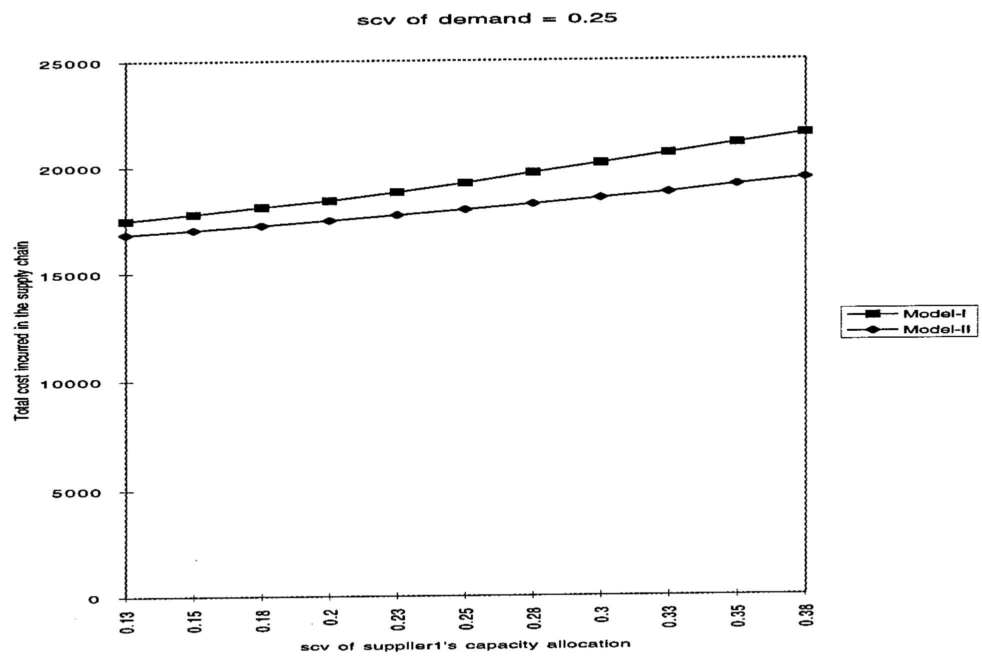

Figure 3: The effect of change in variance of supplier$_1$'s capacity allocation on the total cost incurred in the supply chain

- **Total cost incurred in the supply chain:** We define total cost incurred in the supply chain as the sum of the costs incurred by the suppliers and the holding and 1 costs incurred by the manufacturer. This does not include the cost incurred by the manufacturer in buying the raw materials from the suppliers, as those transaction take place within the supply chain under consideration. Our results indicate that - (1) An increase in demand variability increases the cost incurred for a given value for scv of supplier$_1$'s capacity (refer Table 2). (2) Cost incurred increases with an increase in the variability of supplier$_1$'s capacity (Figure 3) for a given demand variability. (3) Cost incurred by the supply chain in Model-II is (10 to 14.8 %) less than the cost incurred in Model-I (Tables 3 and 4).

- **Quality of service provided:** Quality of service provided by the supply chain is measured based on the percentage of demand satisfied on time (Type-II service measure). Our results indicate that - (1) An increase in demand variability worsens the quality of service for a given value of supplier$_1$'s capacity (Table 2). (2) Quality of service decreases with increase in the scv of supplier$_1$'s capacity (Figure 4) for a given value of demand variability. (3) Model-II outperforms

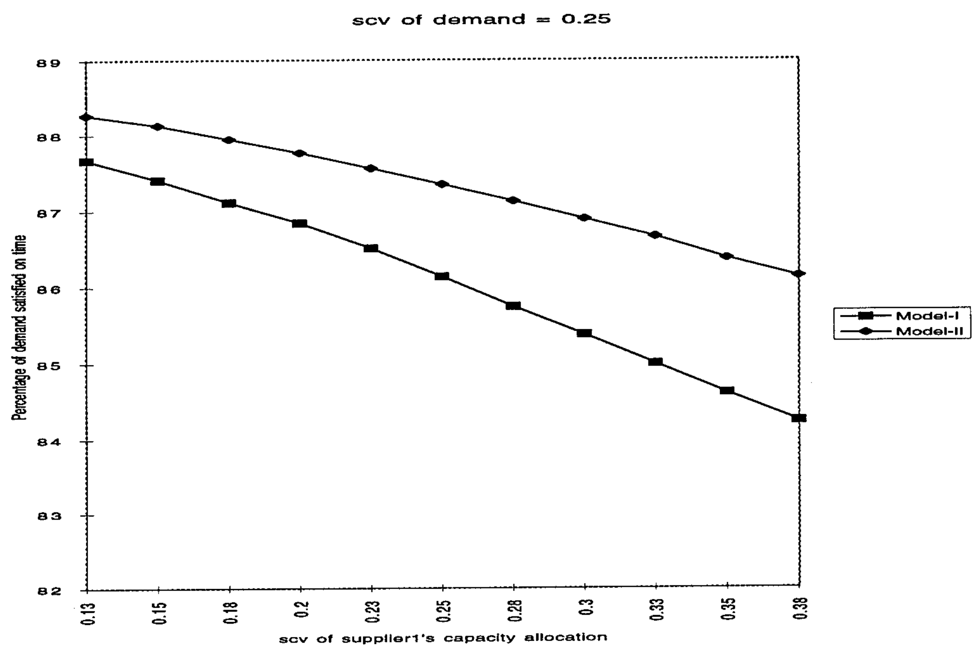

Figure 4: The effect of change in variance of supplier$_1$'s capacity allocation on the quality of services provided by the supply chain

Model-I consistently in terms of quality of service (increases 0.8 to 2.6 %) as shown in Tables 3 and 4.

- **Cost incurred by the manufacturer:** (1) Cost incurred by the manufacturer increases with increase in demand variability for a given value of scv of supplier$_1$'s capacity (Table 2). (2) As shown in Figure 5, increase in the variability of supplier$_1$'s capacity increases the cost incurred by the manufacturer. (3) Cost incurred by the manufacturer is reduced by 2.2 to 5.0% in Model-II as compared to Model-I (Tables 3 and 4). Thus, the manufacturer benefits from information sharing.

- **Profits of suppliers:** (1) Profits of supplier$_1$ decrease with an increase in variability of its capacity in Model-I. However, in Model-II, profits increase with the increase in the variability of supplier$_1$'s capacity. The difference between the profits in Model-I and Model-II ranges from 10.1 to 15.0 % (Figure 6). (2) Profits of supplier$_2$ increase with an increase in the variability of supplier$_1$'s capacity in Model-I. However, in Model-II, profits decrease with an increase in the variability of supplier$_1$'s capacity. The difference between the profits in Model-I and

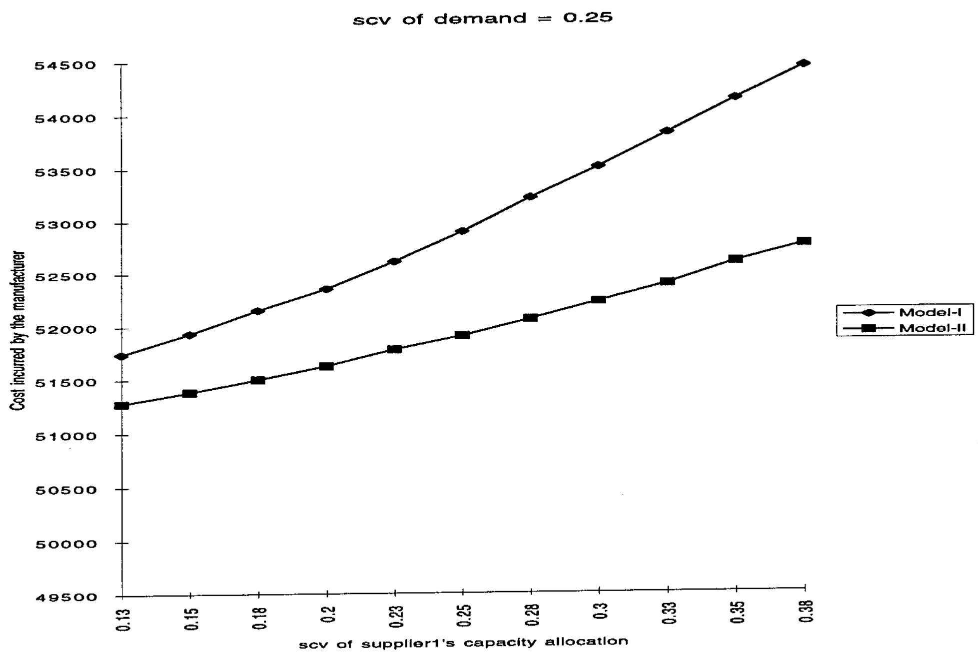

Figure 5: The effect of change in variance of supplier$_1$'s capacity allocation on the cost incurred by the manufacturer

Model-II ranges from 12.0 to 18.1 % (Figure 7). (3) Supplier$_1$'s profit increase with an increase in variance it shows in the capacity allocation for the manufacturer in Model-II. An intuitive explanation for this second order effect is that by increasing the variance in capacity allocation the supplier gets a large slice of the demand in Model-II. However, the increase in profits is not very significant.

The above results on cost and quality of service rendered by the supply chain validate our hypothesis *H1* which states that supplier information sharing leads to better performance in the supply chain both in terms of cost and quality of service. However, our hypothesis *H2* is not validated because supplier$_2$'s profits decrease with information sharing and as a result, we find that supplier information is *not* beneficial to all the organizational entities in the supply chain.[1]

[1]In order to overcome the loss of business from the manufacturer as a result of information sharing, supplier$_2$ should improve the production process (this could be done with or without inputs from the manufacturer) so that it can produce at a lower cost. Dyer and Ouchi[1993] indicate that such situations are common in Japanese automotive industry where 1 like Nissan and Toyota often help a supplier improve the production process in order to reduce cost.

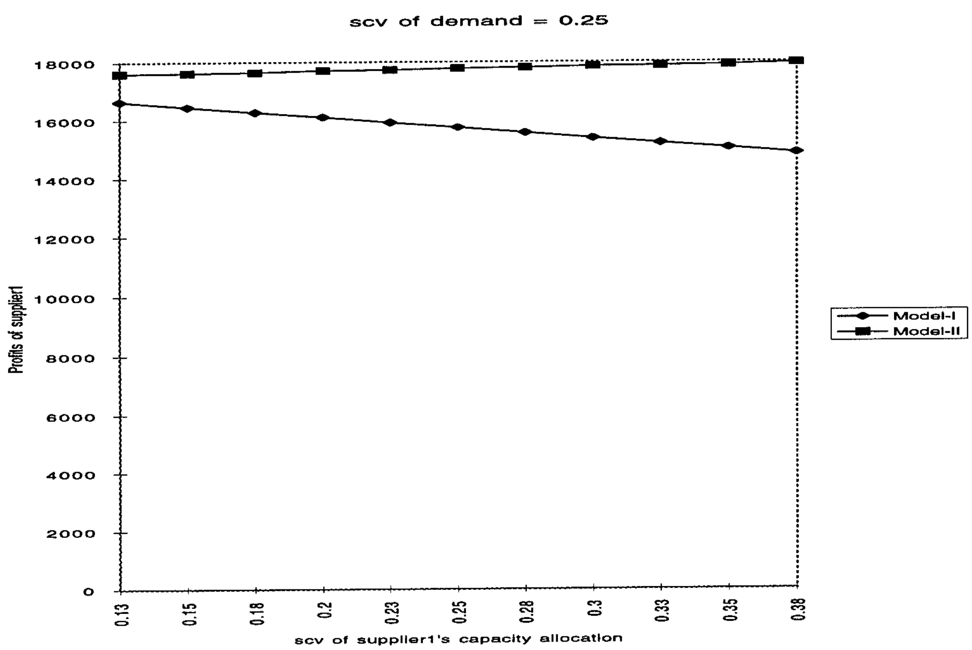

Figure 6: The effect of change in variance of supplier$_1$'s capacity allocation on the profits of supplier$_1$

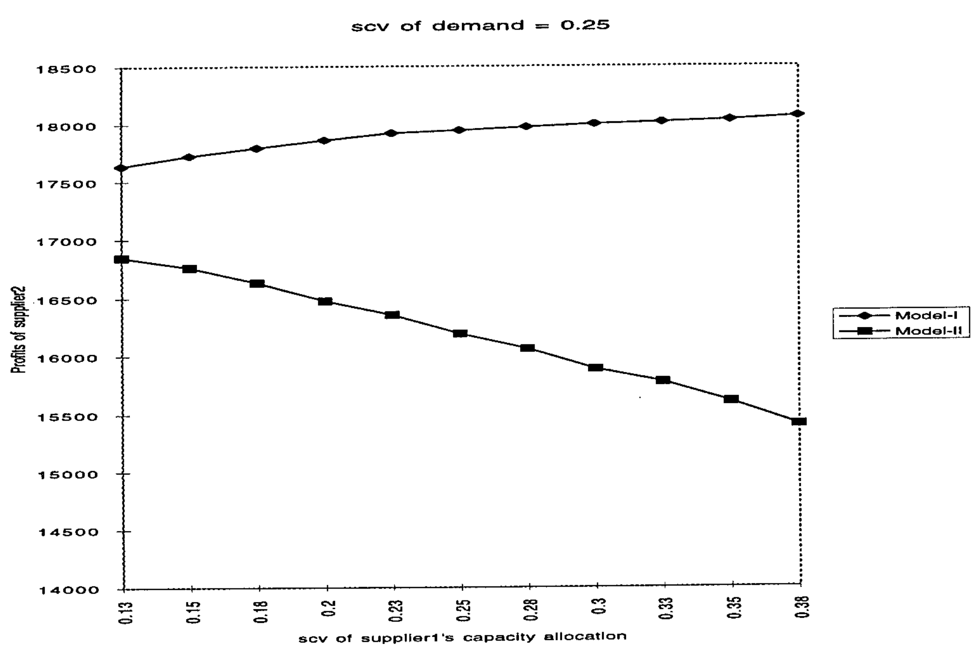

Figure 7: The effect of change in variance of supplier$_1$'s capacity allocation on the profits of supplier$_2$

4.3 Symmetric versus Asymmetric Information Links

From the results of the previous section, we find that the more expensive supplier's profits decrease in Model-II (refer Figure 7). An intuitive explanation for that is that the competitive advantage of supplier_2 is the ability to deliver goods in a more reliable manner as compared to supplier_1. However, in Model-II this advantage of supplier_2 is lost because of the real-time information transfer that occurs between the manufacturer and suppliers. The manufacturer has full information on the capacity allocations before making the reordering decision and uses the information effectively to reduce its cost and provide better services.

σ_1/μ_1	Total Cost	Man. Cost	Service (%)	Supplier_1's Profit	Supplier_2's Profit
0.15	17181	51417	88.2	17623	16612
0.20	17596	51638	87.4	17708	16333
0.25	18119	51929	87.2	17779	16030
0.30	18685	52265	86.3	17850	15729
0.35	19339	52670	86.1	17895	15436

Table 5: Performance of the supply chain under Model-III when scv of demand = 0.25

In such a situation, the manufacturer and supplier_2 have conflicting strategies. The manufacturer prefers information sharing (Model-II) whereas supplier_2 does not prefer information sharing (it prefers Model-I). This may result in asymmetric information links (Model-III) where, the more expensive supplier does not have information links with the manufacturer. We conducted the same set of experiments as in the previous section and compared the performance of Model-II and Model-III. On comparison of tables 4 and 5, we find the following results -

- **Total cost incurred in the supply chain:** Total cost incurred in the supply chain is more in Model-III as compared to Model-II. The difference in cost incurred is less than 3 % for all values of scv of supplier_1's capacity.
- **Quality of service provided:** Percentage of demand satisfied on time is less in Model-III as compared to Model-II. The difference in most cases is less than

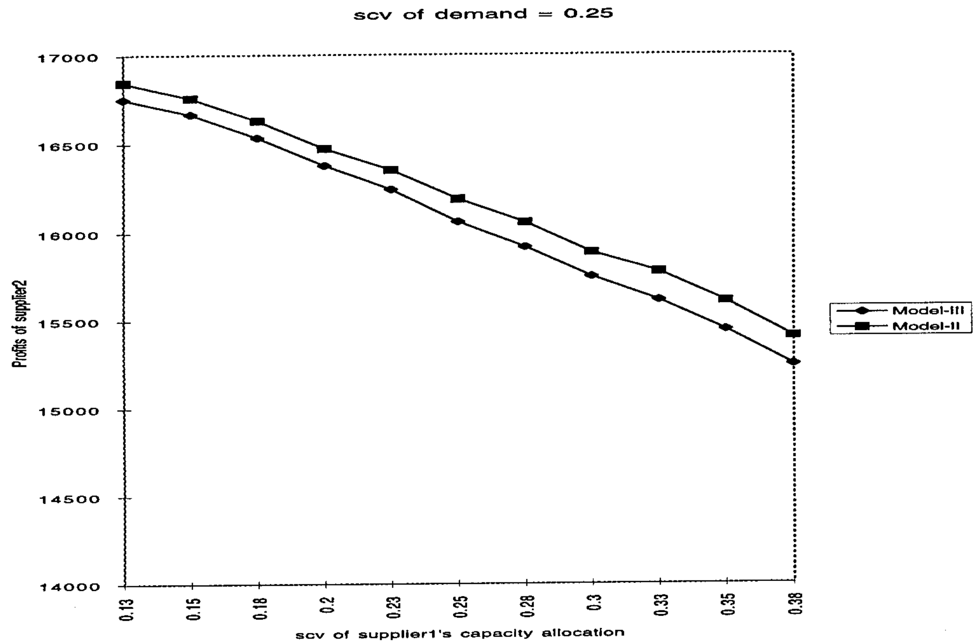

Figure 8: The effect of change in variance of supplier$_1$'s capacity allocation on the profits of supplier$_2$ given that supplier$_1$ shares the information

0.5 % of total demand.

- **Cost incurred by the manufacturer:** Cost incurred by the manufacturer is more in Model-II as compared to Model-III. The difference is marginal and in all cases is less than 0.1 %.

- **Profits of suppliers:** Profits of supplier$_1$ remain the same in both Model-II and Model-III. However, profits of supplier$_2$ is less in Model-III as compared to Model-II (refer Figure 8). This result indicates that it is better for supplier$_2$ to share information given that supplier$_1$ shares the information.

Our results indicate that asymmetric information links (Model-III) is worse for all the entities including the more expensive supplier. As a result, the more expensive supplier is *forced* to share the information because the less expensive supplier is inclined to share the information. These observations validate hypothesis $H3$ which indicates that all entities will be inclined to share information.

4.4 Supplier Adoption Costs

So far we ignored the supplier adoption costs which influenced our results indicating that both suppliers are inclined to share information. In practice, we generally do not find such situations where all entities in the supply chain unilaterally favor such a decision. In this section, we introduce supplier adoption costs in our analysis. On introduction of adoption costs it is not optimal for the suppliers to share information when the adoption costs are greater than the increase in profits due to information sharing. In order to encourage the suppliers to adopt the technology the manufacturer may need to provide subsidies. However, these subsidies may drive the manufacturer towards not having information links if the adoption costs (as a result subsidies) are high.

In our computational study we performed the same set of experiments with different values for the subsidy ($\delta p = 0.01, 0.05, 0.1, 0.15, 0.20, 0.30$ and 0.50). Recall that the values of p_1 and p_2 in all our experiments are 4.5 and 5.5 respectively. It is to be noted that Model-IIs and Model-IIIs (described in section 3.4) are identical to Model-II and Model-III respectively when $\delta p = 0$. We find the following results (summarized in

Subsidy (δp)	Model-I	Model-IIs	Model-IIIs
0.01	52319	51452	51457
0.05	52319	51894	51615
0.10	52319	52248	51813
0.15	52319	52602	52011
0.20	52319	52956	52209
0.30	52319	53664	52605
0.50	52319	55296	53397

Table 6: Comparison of cost incurred by the manufacturer for scv = 0.15 for supplier$_1$'s capacity and scv demand = 0.25

tables 6, 7 and 8).

- (1) Cost incurred by the manufacturer increases with an increase in the subsidy.
- (2) It is better for the manufacturer to have information links with both suppliers

Subsidy (δp)	Model-I	Model-IIs	Model-IIIs
0.01	53334	51970	51978
0.05	53334	52401	52128
0.10	53334	52752	52328
0.15	53334	53102	52528
0.20	53334	53453	52728
0.30	53334	54154	53127
0.50	53334	55816	53926

Table 7: Comparison of cost incurred by the manufacturer for scv = 0.25 for supplier$_1$'s capacity and scv demand = 0.25

Subsidy (δp)	Model-I	Model-IIs	Model-IIIs
0.01	54465	52661	52710
0.05	54465	53088	52872
0.10	54465	53435	53072
0.15	54465	53782	53273
0.20	54465	54128	53475
0.30	54465	54822	53876
0.50	54465	54662	54681

Table 8: Comparison of cost incurred by the manufacturer for scv = 0.35 for supplier$_1$'s capacity and scv demand = 0.25

when price subsidies are low (compare the costs incurred for Model-I, Model-IIs and Model-IIIs when $\delta p < 0.05$).

- (3) It is better for the manufacturer to have information links with the less expensive supplier when price subsidies are moderate (compare the costs when $0.05 \leq \delta p < 0.5$ (for scv of supplier$_1$'s capacity = 0.25, 0.35) and when $0.05 \leq \delta p < 0.3$ (for scv of supplier$_1$'s capacity =0.15)).

- (4) It is better for the manufacturer to have no information links when price subsidies are high (compare the costs when $\delta p \geq 0.5$ (for scv of supplier$_1$'s capacity =0.25, 0.35) and $\delta \geq 0.3$ (for scv of supplier$_1$'s capacity = 0.15)).

Manufacturer's decision to adopt information links with the suppliers depends on the subsidy (δp) and the variation of supplier$_1$'s capacity allocation. When the subsidy value is low (supplier adoption costs are low) then it is better to have information links with both the suppliers. When the subsidy value is moderate then it is better to have information links with the less expensive supplier and when subsidy value is very high, it is better not to have information links. [Wang and Seidmann(1995)] show a similar result for a deterministic demand. They prove that if the supplier adoption costs for information links (EDI links) are high then it is optimal for the manufacturer to have EDI only with few suppliers. Our results provide one possible explanation for a supplier's preference to join the 1 (because supplier adoption costs are relatively low) whereas EDI links with specific manufacturers are not as prevalent (because supplier adoption costs are higher). Our results provide further insights on the incentive for the manufacturer to have information links. We find from results (3) and (4) that the manufacturer is likely to maintain information links with suppliers when the uncertainty in the supply process is greater even if the supplier adoption costs are high. Based on the above results we find that incorporation of supplier adoption costs may result in the negation of hypotheses $H?$ and $H3$ based on the amount of subsidy (δp) and the variation in supplier$_1$'s capacity allocation.

5 Conclusions

In this paper, we analyze the effect of supplier available-to-promise (ATP) information on the performance of a supply chain. We integrate supplier information with

the decision process of the manufacturer. We first develop a basic model for manufacturer/supplier interaction in a simple two-tiered supply chain, and derive an optimal ordering policy for the manufacturer. We provide a newsboy interpretation to the policy and generalize it to multiple suppliers. We then use the basic model (with two suppliers) to define a series of more specialized models, each making different assumptions about the extent and costs of supplier information exchange. Through our computational study, we have tried to understand the dynamics of the supply chain using different parameters for demand and capacity variations. While it is impossible to generalize completely, our study indicates that supplier information has a significant effect on the performance of different entities present in the supply chain. We find that information sharing reduces the total cost incurred in the supply chain and improves the quality of service. These results confirm the belief that quick propagation of relevant information reduces uncertainty in the system and, as a result, leads to better performance. We find that the more expensive supplier may not benefit from information sharing, yet is *forced* to share information. The less expensive supplier and the manufacturer benefit from information sharing (when supplier adoption costs are neglected). Thus, we find that inter-organizational information systems (IOS) may not be beneficial to all entities in the supply chain. Introduction of price subsidies (to model supplier adoption costs) changes the effect of information sharing on the performance of the manufacturer. We find that it may no longer be optimal for the manufacturer to share information with both suppliers. We also find that the manufacturer is likely to maintain information links with suppliers when uncertainty in the supply process is greater even if supplier adoption costs are high. Our results provide further insights into diversity of interests which lead to difficulties in the adoption of inter-organizational information systems in a supply chain.

In this paper, we considered a single period optimization by the manufacturer and simulated the policy for a number of periods. Some extensions of this model are as follows. (1) A multi-period model for the manufacturer would facilitate understanding the relationship between performance of entities in the supply chain and number of periods in the decision process. In such a model, we need to incorporate the inaccuracy in information provided in such a manner so that inaccuracy in capacity information for a future period increases as we move away from the current period. (2) In this paper, we assumed that suppliers face demand from other manufacturers as well. In

most cases these manufacturers are part of the same industry. As a result, demand that the manufacturer (in our model) faces and capacity allocations of suppliers would be highly correlated. It would be interesting to analyze the impact of information sharing in such a situation. (3) Finally, a two stage model of the supply chain is useful to get insightful analytical results but may not be a very close approximation to a real life supply chain. A multi-level modeling of the supply chain (with some approximations on the operating strategies) may provide additional insights on the impact of information sharing.

References

ANUPINDI, R. AND AKELLA, R., *Diversification Under Supply Uncertainty*, Management Science, vol. 39, no. 8, 1993, 944-963.

BASSOK, Y. AND AKELLA, R., *Ordering and Production Decisions with Supply and Demand Uncertainty*, Management Science, vol. 37, no. 12, 1991, 1556-1574.

CASH, J.I. AND KONSYNSKI, B.R., *IS redraws competitive boundaries*, Harvard Business Review, vol. 63, no. 2, 1985, 134-42.

COHEN, M.A. AND LEE, H.L., *Strategic Analysis of Integrated Production-Distribution Systems: Models and Methods*, Journal of Operations Research, vol. 36, no. 2, 1988, 216-228.

COLE, R. AND YAMAKUSHIJI, K., *The US and Japanese Automotive Industries in Transition*, Joint US-Japan Automotive Study, Ann Arbor, Michigan, 1984.

DYERS, H.J. AND OUCHI, W.G., *Japanese-Style Partnerships: Giving Companies a Competitive Edge*, Sloan Management Review, vol. 35, no. 1, 1993, 51-64.

EFFICIENT CONSUMER RESPONSE REPORT (ECR), *Enhancing Consumer Value in the Grocery Industry*, Kurt Solomon Associates Inc., Food Marketing Institute, 1993.

HARMON, R.L., *Reinventing the Factory-II*, New York, Free Press, 1992, 107-153.

HORNBACK, R.,*An EDI costs/benefit framework*, Systems Management, vol. 22, no. 10, 1994, 82-88.

HELPER, S., *How much has really changed between US 1 and their suppliers ?*, Sloan Management Review, vol. 32, no. 4, 1991, 15-28.

HELPER, S. AND SAKO, M., *Supplier Relations in Japan and the United States: Are They Converging ?*, Sloan Management Review, vol. 36, no. 3, 1995, 77-85.

KELLEHER, J.,*Electronic Data Interchange: Standard's Momentum Grows as Users Realize Benefits.*, ComputerWorld, September 22, 1986.

KLEIN, S., *Technical, Organizational and Managerial Aspects of Implementing EDI: Results and Experiences of 12 EDI Projects*, Evaluation Report of the Commission to the European Communities, 1992.

LAU, H. AND LAU, A.H., *Coordinating Two Suppliers with Offsetting Leadtime and Process Performance*, Journal of Operations Management, vol. 11, no. 4, 1994, 327-337.

LEE, H.L. AND BILLINGTON, C., *Managing Supply Chain Inventory : Pitfalls and Opportunities*, Sloan Management Review, vol. 33, no. 3, 1992, 65-73.

LEE, H.L. AND BILLINGTON, C., *Material Management in Decentralized Supply Chains*, Journal of the Operation Research, vol. 41, no. 5, 1993, 835-847.

MARKUS, M.L., *Toward a Critical Mass Theory of Interactive Media*, Organizations and Communications Technology, Sage Publications, 1990, 194-218.

MOINZADEH, K. AND NAHMIAS, S., *A Continuous Review Model for an Inventory System with Two Supply Nodes*, Management Science, vol. 34, no. 6, 1988, 761-773.

OREN, S.S. AND SMITH, S.S., *Critical Mass and Tariff Structure in Electronic Com-*

munications Markets, The Bell Journal of Economics, vol. 12, no. 2, 1981, 467-487.

PYKE, D.F., AND COHEN, M.A., *Performance Characteristics of Stochastic Integrated Production-Distribution Systems*, European Journal of Operations Research, vol. 68, no. 1, 1993, 23-48.

PYKE, D.F., AND COHEN, M.A., *Multiproduct Integrated Production Distribution Systems*, European Journal of Operations Research, vol. 74, no. 1, 1994, 18-49.

RAMASESH, R.V., ORD, J.K., HAYYA, J.C. AND PAN, A., *Sole versus Dual Sourcing in Stochastic Lead-Time(s,Q) Inventory Models*, Management Science, vol. 37, no. 4, 1991, 428-443.

RAMASESH, R.V., ORD, J.K. AND HAYYA, J.C., *Dual Sourcing with Non-identical Suppliers*, Naval Research Logistics, vol. 40, no. 2, 1993, 279-288.

RIGGINS, F.J., KRIEBAL, C.H. AND MUKHOPADHYAY, T.,*The Growth of Interorganizational Systems in the Presence of Demand Externalities*, Management Science, vol. 40, no. 8, 1994, 984-98.

SRINIVASAN, K., KEKRE, S. AND MUKHOPADHYAY, T., *Impact of Electronic Data Interchange Technology on JIT Shipments*, Management Science, vol. 40, no. 10, 1994, 1291-1305.

UDO, G.J., *The Impact of Telecommunications on Inventory Management*, Production and Inventory Management Journal, vol. 34, no. 2, 1993, 32-37.

WANG, E.T.G. AND SEIDMANN, A., *Electronic Data Interchange: Competitive Externalities and Strategic Implementation Policies*, Management Science, vol. 41, no. 3, 1995, 401-418.

WOMACK, J.P., JONES, D.T. AND ROOS, D., *The Machine that Changed the World*, New York, Rawson Associates, 1990.

Appendix

Proof of Proposition 2.1 $M(x, w_1, w_2) = p_1 w_1 \beta_1(w_1) + p_2 w_2 \beta_2(w_2) + p_1 \gamma_1 \overline{\beta}_1(w_1) + p_2 \gamma_2 \overline{\beta}_2(w_2)$ $+$

$$\begin{aligned}
&\pi\beta_1(w_1)\overline{\beta}_2(w_2)\int_{x+w_1+\gamma_2}^{\infty}(\xi - x - w_1 - \gamma_2)f(\xi)d\xi\ + \\
&\pi\beta_1(w_1)\beta_2(w_2)\int_{x+w_1+w_2}^{\infty}(\xi - x - w_1 - w_2)f(\xi)d\xi + \\
&\pi\overline{\beta}_1(w_1)\overline{\beta}_2(w_2)\int_{x+\gamma_1+\gamma_2}^{\infty}(\xi - x - \gamma_1 - \gamma_2)f(\xi)d\xi + \\
&\pi\overline{\beta}_1(w_1)\beta_2(w_2)\int_{x+\gamma_1+w_2}^{\infty}(\xi - x - \gamma_1 - w_2)f(\xi)d\xi\ + \\
&h\beta_1(w_1)\overline{\beta}_2(w_2)\int_0^{x+w_1+\gamma_2}(x + w_1 + \gamma_2 - \xi)f(\xi)d\xi\ + \\
&h\beta_1(w_1)\beta_2(w_2)\int_0^{x+w_1+w_2}(x + w_1 + w_2 - \xi)f(\xi)d\xi\ + \\
&h\overline{\beta}_1(w_1)\overline{\beta}_2(w_2)\int_0^{x+\gamma_1+\gamma_2}(x + \gamma_1 + \gamma_2 - \xi)f(\xi)d\xi\ + \\
&h\overline{\beta}_1(w_1)\beta_2(w_2)\int_0^{x+\gamma_1+w_2}(x + \gamma_1 + w_2 - \xi)f(\xi)d\xi
\end{aligned}$$

$$\begin{aligned}
\frac{\partial^2 M(x,w_1,w_2)}{\partial x^2} &= (\pi + h)(\beta_1(w_1)\beta_2(w_2)f(x + w_1 + w_2) + \beta_1(w_1)\overline{\beta}_2(w_2)f(x + w_1 + \gamma_2) + \\
&\quad \overline{\beta}_1(w_1)\overline{\beta}_2(w_2)f(x + \gamma_1 + \gamma_2) + \beta_2(w_2)\overline{\beta}_1(w_1)f(x + w_2 + \gamma_1))
\end{aligned}$$

$$\begin{aligned}
\frac{\partial^2 M(x,w_1,w_2)}{\partial w_1^2} = \frac{\partial^2 M(x,w_1,w_2)}{\partial w_1 \partial x} &= (\pi + h)(\beta_1(w_1)\beta_2(w_2)f(x + w_1 + w_2) + \\
&\quad \beta_1(w_1)\overline{\beta}_2(w_2)f(x + w_1 + \gamma_2))
\end{aligned}$$

$$\begin{aligned}
\frac{\partial^2 M(x,w_1,w_2)}{\partial w_2^2} = \frac{\partial^2 M(x,w_1,w_2)}{\partial w_2 \partial x} &= (\pi + h)(\beta_1(w_1)\beta_2(w_2)f(x + w_1 + w_2) + \\
&\quad \beta_2(w_2)\overline{\beta}_1(w_1)f(x + w_2 + \gamma_1))
\end{aligned}$$

$$\frac{\partial^2 M(x,w_1,w_2)}{\partial w_2 \partial w_1} = \frac{\partial^2 M(x,w_1,w_2)}{\partial w_1 \partial w_2} = (\pi + h)(\beta_1(w_1)\beta_2(w_2)f(x + w_1 + w_2))$$

The Hessian H is given by,

$$H = \begin{vmatrix} \frac{\partial^2 M(x,w_1,w_2)}{\partial w_1^2} & \frac{\partial^2 M(x,w_1,w_2)}{\partial w_1 \partial w_2} & \frac{\partial^2 M(x,w_1,w_2)}{\partial w_1 \partial x} \\ \frac{\partial^2 M(x,w_1,w_2)}{\partial w_2 \partial w_1} & \frac{\partial^2 M(x,w_1,w_2)}{\partial w_2^2} & \frac{\partial^2 M(x,w_1,w_2)}{\partial w_2 \partial x} \\ \frac{\partial^2 M(x,w_1,w_2)}{\partial w_1 \partial x} & \frac{\partial^2 M(x,w_1,w_2)}{\partial w_2 \partial x} & \frac{\partial^2 M(x,w_1,w_2)}{\partial x^2} \end{vmatrix}$$

Define $a = \frac{\partial^2 M(x,w_1,w_2)}{\partial w_2 \partial w_1}$; $b = \frac{\partial^2 M(x,w_1,w_2)}{\partial w_1^2}$; $c = \frac{\partial^2 M(x,w_1,w_2)}{\partial x^2}$; $d = \frac{\partial^2 M(x,w_1,w_2)}{\partial x^2}$
Let,
$b = a + b_1$ where $b_1 = (\pi + h)\beta_1(w_1)\overline{\beta}_2(w_2)f(x + w_1 + \gamma_2)$
$c = a + c_1$ where $c_1 = (\pi + h)\overline{\beta}_1(w_1)\beta_2(w_2)f(x + \gamma_1 + w_2)$
$d = a + b_1 + c_1 + d_1$ where $d_1 = (\pi + h)\overline{\beta}_1(w_1)\overline{\beta}_2(w_2)f(x + \gamma_1 + \gamma_2)$
The determinant of H is given by,
$\det H = (a+b_1)(a+c_1)(b_1+d_1) - a(a.d_1 - b_1.c_1) - (a+b_1)(a+c_1)b_1 = b_1.c_1(a+d_1) + a.d_1(b_1+c_1)$
Since each of the terms, b_1, c_1, a, d_1 are non-negative, the Hessian is positive semi-definite and therefore the function is convex. □

Proof of Proposition 2.2:
From Proposition 2.1, we know that the single period cost function is convex. For the optimal values for w_1 and w_2, we need to find the partial derivatives of $M(x, w_1, w_2)$ with respect to

them and apply the Kuhn-Tucker conditions. The first order optimality conditions are: for i= 1,2

$$\frac{\partial M}{\partial w_i} >= 0 \qquad \text{and} \qquad w_i(\frac{\partial M}{\partial w_i}) = 0$$

There are three possible ways of ordering goods from the suppliers, a) order no goods from both of them, b) order goods only from the more economical supplier and c) order goods from both the suppliers. Lets consider these cases.

Case-I: $w_1 = w_2 = 0$

$\frac{\partial M(x,w_1,w_2)}{\partial w_1} = p_1 - \pi + (\pi + h).F(x)$

This value is less than 0, but in the limit when x tends to infinity the value becomes greater than 0. Hence, there exists a point where the derivative is 0. Thus,

$x_1 = F^{-1}(\frac{\pi - p_1}{\pi + h})$

Similarly,

$\frac{\partial M(x,w_1,w_2)}{\partial w_2} = p_2 - \pi + (\pi + h).F(x)$

Using similar arguments as above, we can get another point x_2 where,

$x_2 = F^{-1}(\frac{\pi - p_2}{\pi + h})$

We know that the first supplier is less expensive as compared to the second supplier, i.e $p_1 < p_2$, therefore, $x_1 > x_2$.So, we have a value of on-hand inventory x such for $x > F^{-1}(\frac{\pi - p_1}{\pi + h})$, the optimal policy is not to order goods from either of the suppliers, i.e w_1=w_2=0.

Case-II: $w_1 > 0$ and $w_2 = 0$

As $w_1 > 0$ hence, $\frac{\partial M(x,w_1,w_2)}{\partial w_1}$ at $w_2 = 0$ is zero by the Kuhn-Tucker conditions.

$p_1\beta_1(w_1) - \pi\beta_1(w_1) + (\pi + h)\beta_1(w_1)F(x + w_1) = 0$

which implies that

$\beta_1(w_1) = 0 \qquad \text{or} \qquad F(x + w_1) = \frac{\pi - p_1}{\pi + h}$

We also know that $w_2 = 0$ which implies that $\frac{\partial M(x,w_1,w_2)}{\partial w_2} >= 0$ so, two alternate cases need to be considered,

if $\beta_1(w_1)$=0 then, $w_1 = \gamma_1$

because the maximum goods that can be expected to be delivered when $\beta_1(w_1)$ is equal to zero has a upper bound of γ_1, so it would be optimum to order only γ_1.

If $\beta_1(w_1)$ is not equal to zero then we get, $w_1 = F^{-1}(\frac{\pi - p_1}{\pi + h}) - x$

So, if we have values of on-hand inventory x such that

$$x >= F^{-1}(\frac{\pi - p_2}{\pi + h}) - \gamma_1 \qquad \text{and} \qquad x <= F^{-1}(\frac{\pi - p_1}{\pi + h})$$

then it would be optimal to order min $(\gamma_1, F^{-1}(\frac{\pi - p_1}{\pi + h}) - x)$ from the more economical supplier and nothing from the other supplier.

Case-III: $w_1 > 0$ and $w_2 > 0$

Applying the first order conditions we get,

$$\frac{\partial M(x,w_1,w_2)}{\partial w_1} = p_1\beta_1(w_1) - \pi\beta_1(w_1) + (\pi + h)(\beta_1(w_1)\beta_2(w_2)F(x + w_1 + w_2) + \beta_1(w_1)\overline{\beta}_2(w_2)F(x + w_1 + \gamma_2) = 0$$

and,

$$\frac{\partial M(x,w_1,w_2)}{\partial w_2} = p_2\beta_2(w_2) - \pi\beta_2(w_2) + (\pi + h)(\beta_1(w_1)\beta_2(w_2)F(x + w_1 + w_2) + \beta_2(w_2)\overline{\beta}_1(w_1)F(x + w_2 + \gamma_1) = 0$$

Solving the above simultaneous equation, leads to the optimal order quantities w_1 and w_2 from the suppliers.
The value of a, b and w_{1a}^* are given by:
$a = F^{-1}(\frac{\pi - p_1}{\pi + h})$,

$b = F^{-1}(\frac{\pi - p_2}{\pi + h}) - \gamma_1$, and

$w_{1a}^* = min(\gamma_1, F^{-1}(\frac{\pi - p_1}{\pi + h}) - x)$
The values of w_{1b}^* and w_{2a}^* should satisfy the above simultaneous equation (given in case-III). We proceed by splitting the possible values into four regions based on whether $\beta_i(w_i) = 0$ or 1 for i= 1,2. Then we get the following rule -

If $F^{-1}(\frac{\pi - p_2}{\pi + h}) - \gamma_1 - x < \gamma_2$
then

$$w_{1b}^* = \gamma_1; \qquad w_{2a}^* = F^{-1}(\frac{\pi - p_2}{\pi + h}) - \gamma_1 - x$$

else

$$w_{1b}^* = \gamma_1; \qquad w_{2a}^* = \gamma_2 \ \square$$